The Wind-Evaporation-SST Feedback for Latitudinal Asymmetry of the ITCZ: Observational Evidence

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Submitted to *Geophys. Res. Lett.*
March 2007

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Abstract

Theoretical studies have suggested that the wind-evaporation-SST (WES) feedback plays an important role in maintaining the latitudinal asymmetry of the Intertropical Convergence Zone (ITCZ). This study presents observational evidence of the WES feedback, especially the spatial distribution of its strength. The results show that the WES feedback is most prominent over western and central Pacific, western Atlantic and Indian oceans, where for an 1 ^{o}C increase in interhemispheric SST difference, the latent heat flux in northern hemisphere and/or southern hemisphere changes by about 10-20 Wm^{-2}. However, the WES feedback is weak over eastern Pacific and eastern Atlantic oceans. These results provide a baseline for evaluating the spatial distribution and strength of the WES feedback in general circulation models.

1. Introduction

An important question for tropical mean climate is why the annual mean Intertropical Convergence Zone (ITCZ) is located north of the equator in the central Pacific, eastern Pacific and Atlantic Oceans, although the annual mean solar radiation is symmetric about the equator and has its maximum on the equator. Previous theoretical studies suggested that ocean-atmosphere feedback plays an important role in maintaining this latitudinal asymmetry of tropical mean climate (see review by Xie 2005). There are two major ocean-atmosphere feedback mechanisms: the wind-evaporation-SST (WES) feedback (Xie and Philander 1994; Xie 1996a) and the stratus-SST feedback (Philander et al. 1996 Ma et al. 1996; Yu and Mechoso 1999; Gordon et al. 2000; de Szoeke et al. 2006), which enhance the meridional asymmetry associated with the continental forcing in the eastern boundary (e.g. Xie 1996a; Xie and Saito 2001), seasonal solar forcing (e.g. Xie 1996b), and atmosphere's internal dynamics (e.g. Charney 1971; Holton 1971; Lindzen 1974; Waliser and Somerville 1994; Chao 2000; Chao and Chen 2001, 2004; Liu and Xie 2002; Bacmeister et al. 2006; Chao et al. 2006).

Xie and Philander (1994) proposed the WES feedback mechanism for breaking the equatorial symmetry set by solar radiation (see schematic in Fig. 4-5 of Xie 2005). Suppose that somehow the sea surface temperature (SST) north of the equator becomes slightly warmer than to the south. The sea level pressure (SLP) gradient will drive southerly winds across the equator. The Coriolis force acts to turn these southerlies westward south and eastward north of the equator. Superimposed on the background easterly trade winds, the anomalous westerly winds north of the equator decrease surface wind speed and hence latent heat flux (LHF), while the anomalous easterly winds south of the equator increase surface wind speed and associated LHF. These changes in LHF amplify the initial interhemispheric SST difference, and thus provide a positive feedback to the latitudinal asymmetry. However, this mechanism has not been tested using observational data.

The purpose of this study is to test the WES feedback mechanism using observational data. The questions we address are:

(1) Does the WES feedback exist in the real atmosphere? In which ocean basin/region is it most prominent? For example, is the WES feedback prominent over the eastern Pacific where the strongest latitudinal asymmetry of the ITCZ exists?

(2) How large is the feedback parameter, i.e., for a given change in interhemispheric SST difference, how much do the latent heat fluxes change? This is important for evaluating quantitatively the strength of WES feedback in general circulation models (GCMs), many of which have the double-ITCZ problem with unrealistic ITCZs in the southern hemisphere (e.g. Lin 2006).

The observational datasets used in this study are described in section 2. Results are presented in section 3. A summary and discussion are given in section 4.

2. Data

We use 21 years (1979-1999) of monthly datasets of SST, precipitation, surface winds and latent heat flux. For each variable, different datasets are used whenever possible in order to sample the uncertainties associated with measurement/retrieval/analysis. The datasets used include:

(1) SST from the Extended Reconstruction of SST (ERSST; Smith and Reynolds 2004) and the Met Office Hadley Centre's Sea Ice and SST (HADISST; Rayner et al. 2003), both with a horizontal resolution of 1 degree longitude by 1 degree latitude,

(2) precipitation from the Global Precipitation Climatology Project (GPCP) Version 2 data (Adler et al. 2003) with a horizontal resolution of 2.5 degree longitude by 2.5 degree latitude, and

(3) surface winds and latent heat flux from the NCEP/NCAR reanalysis (Kalnay et al. 1996) and ECMWF 40-year reanalysis (ERA40; Gibson et al. 1997), both with a horizontal resolution of 2.5 degree longitude by 2.5 degree latitude.

Because we are interested only in the large-scale features, all datasets are averaged to have a zonal resolution of 10 degrees longitude but the original meridional resolutions are kept.

3. Results

Our analysis follows step-by-step the WES feedback loop as discussed in the introduction. First we look at how the interhemispheric SST difference affects the off-equatorial precipitation. Figure 1 shows the linear regression of monthly data for (a) 5N-15N, and (b) 5S-15S averaged precipitation vs the interhemispheric SST difference (ΔSST), which is defined as the difference between the 5N-15N averaged SST and the 5S-15S averaged SST. Precipitation in the northern hemisphere (NH) increases with ΔSST increase in all three ocean basins, with three broad maxima over Indian Ocean, eastern Pacific, and Atlantic Ocean (Figure 1a). A 1 C increase in ΔSST generally leads to more than 1 mm/day increase in precipitation. On the contrary, precipitation in the southern hemisphere (SH) decreases with ΔSST increase in all three basins, although the magnitude is smaller than in NH over Indian Ocean, eastern Pacific, and Atlantic Ocean (Figure 1b). The small precipitation response in the SH over eastern Pacific and Atlantic oceans may be related to the lack of deep convection in those regions.

Precipitation is the dominant term of vertically-integrated diabatic heating in the troposphere. Consistent with the amplifying (weakening) of heating in NH (SH), the cross-equatorial meridional wind v (Figure 2) is enhanced in all three basins, with a magnitude of 0.5-2.0 m/s for 1 C increase in ΔSST. This is accompanied by a 0.5-3 m/s enhancement of zonal wind u in NH in all three basins (Figure 3a) and a 0.5-2.5 m/s decrease of u in SH over Indian Ocean and western Pacific (Figure 3b). The zonal distribution of u anomaly over Indian and Pacific Oceans is quite similar to that of precipitation anomaly, in both the NH and SH (Figure 1).

Whether the u anomaly enhances or suppresses the wind speed is affected by the time-mean background u wind. If the time-mean u is easterly, an easterly (westerly) u anomaly will enhance (suppress) the wind speed. Figure 4 shows the annual mean u wind averaged between (a) 5N-15N, and (b) 5S-15S. The time-mean u wind is easterly over most of the tropics, and is westerly only over northern Indian Ocean and eastern Atlantic in the NH. Consistent with the u anomaly (Figure 3) and time-mean u (Figure 4), wind speed decreases with ΔSST increase over Pacific and western Atlantic Oceans in the NH, but increases with ΔSST increase over Indian Ocean in the NH and over all three basins in the SH (Figure 5).

The changes in LHF (Figure 6a, Figure 6b) are quite consistent with those in wind speed (Figure 5a, Figure 5b), with LHF decreasing with ΔSST increase over Pacific and western Atlantic Oceans in the NH, but increasing with ΔSST increase over Indian Ocean in the NH and over all three basins in the SH. Therefore the WES feedback does exist in the real atmosphere. It is prominent over western and central Pacific, western Atlantic and Indian oceans, where for an 1 ^{o}C increase in interhemispheric SST difference, the latent heat flux in northern hemisphere and/or southern hemisphere changes by about 10-20 Wm^{-2}. However, the WES feedback is weak over eastern Pacific and eastern Atlantic oceans, where strong latitudinal asymmetry of the ITCZ exists. In these regions, some other mechanisms, such as continental forcing (Xie 1996a) may play an important role in maintaining the latitudinal asymmetry.

4. Summary

Theoretical studies have suggested that the WES feedback plays an important role in maintaining the latitudinal asymmetry of the ITCZ. This study presents observational evidence of the WES feedback including the spatial distribution of its strength. The results show that the WES feedback is most prominent over western and central Pacific, western Atlantic and Indian oceans, where for an 1 ^{o}C increase in interhemispheric SST difference, the latent heat flux in northern hemisphere and/or southern hemisphere changes by about 10-20 Wm^{-2}. However, the WES feedback is weak over eastern Pacific and eastern Atlantic oceans.

The results of current study provide a baseline for evaluating *quantitatively* the strength of WES feedback in the GCMs to understand the physical mechanism the double-ITCZ problem. In a companion paper, Lin (2006) evaluates the strength of WES feedback in 12 atmospheric GCMs participating in the Inter-governmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), and found that most of the models simulate an overly strong WES feedback. However, Lin (2006) does not analyze why the WES feedback is too strong in the models. In the future, analyses such as those in this paper can be the first step for exploring the underlying physical mechanisms.

Acknowledgements

This study was supported by the NOAA CPO/CVP Program, NOAA CPO/CDEP Program, and NASA Modeling, Analysis and Prediction (MAP) Program.

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FIGURE CAPTIONS

Figure 1. Linear regression of monthly data for (a) 5N-15N and (b) 5S-15S averaged precipitation vs interhemispheric SST difference (ΔSST).

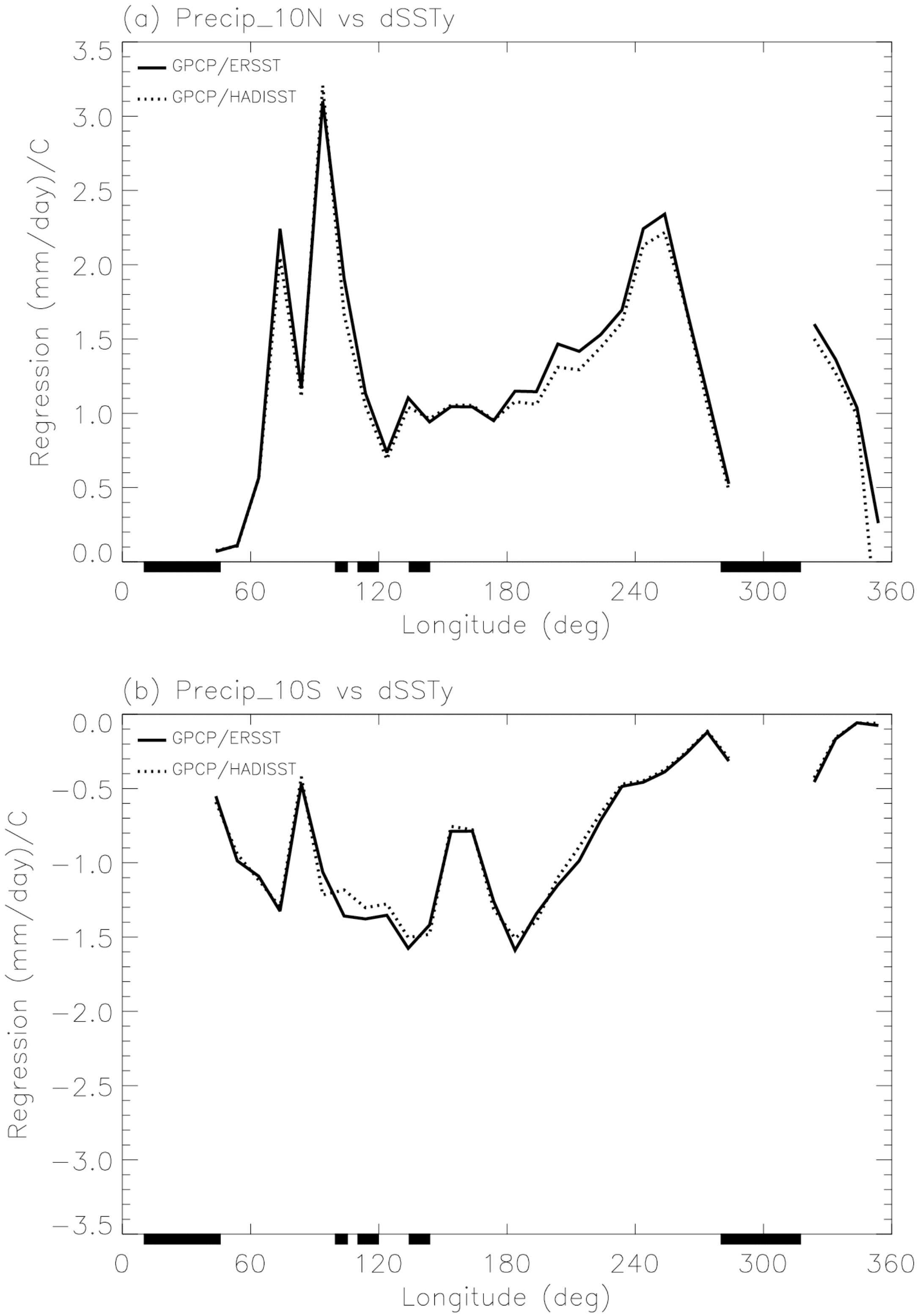
Figure 2. Same as Figure 1 but for 5N-5S averaged v vs ΔSST.

Figure 3. Same as Figure 1 but for (a) 5N-15N, and (b) 5S-15S averaged u vs ΔSST.

Figure 4. Annual mean u averaged between (a) 5N-15N, and (b) 5S-15S.

Figure 5. Same as Figure 1 but for (a) 5N-15N, and (b) 5S-15S averaged wind speed vs ΔSST.

Figure 6. Same as Figure 1 but for (a) 5N-15N averaged LHF, and (b) 5S-15S averaged LHF vs ΔSST.



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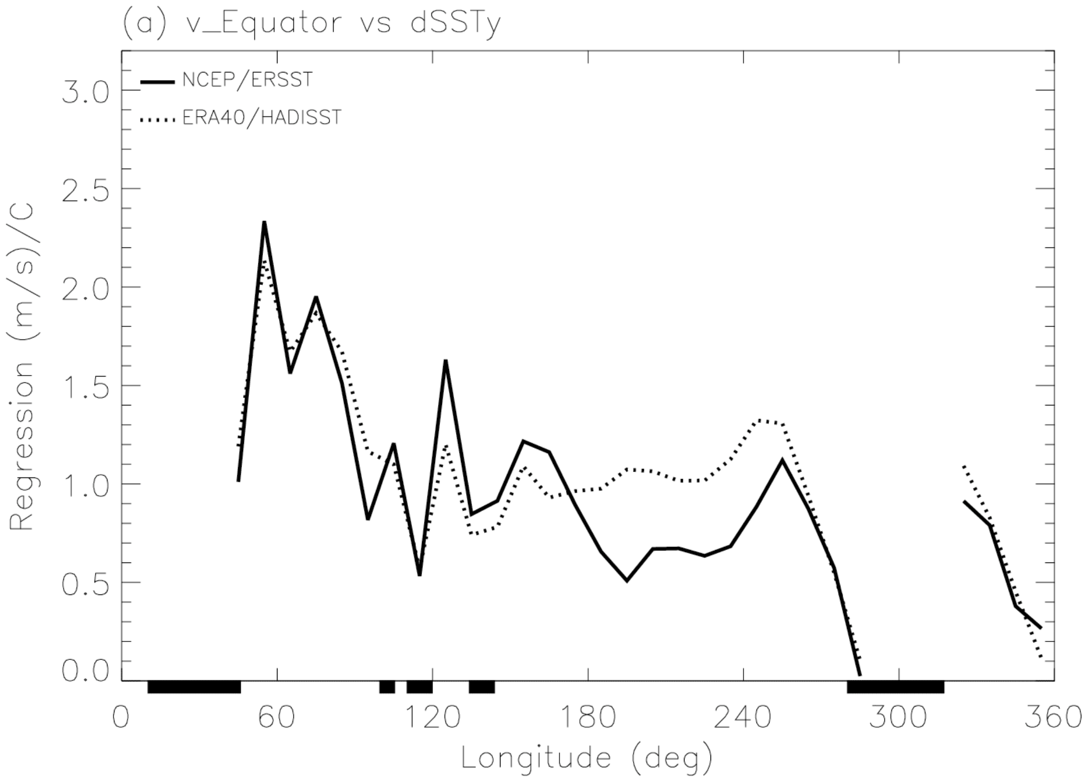

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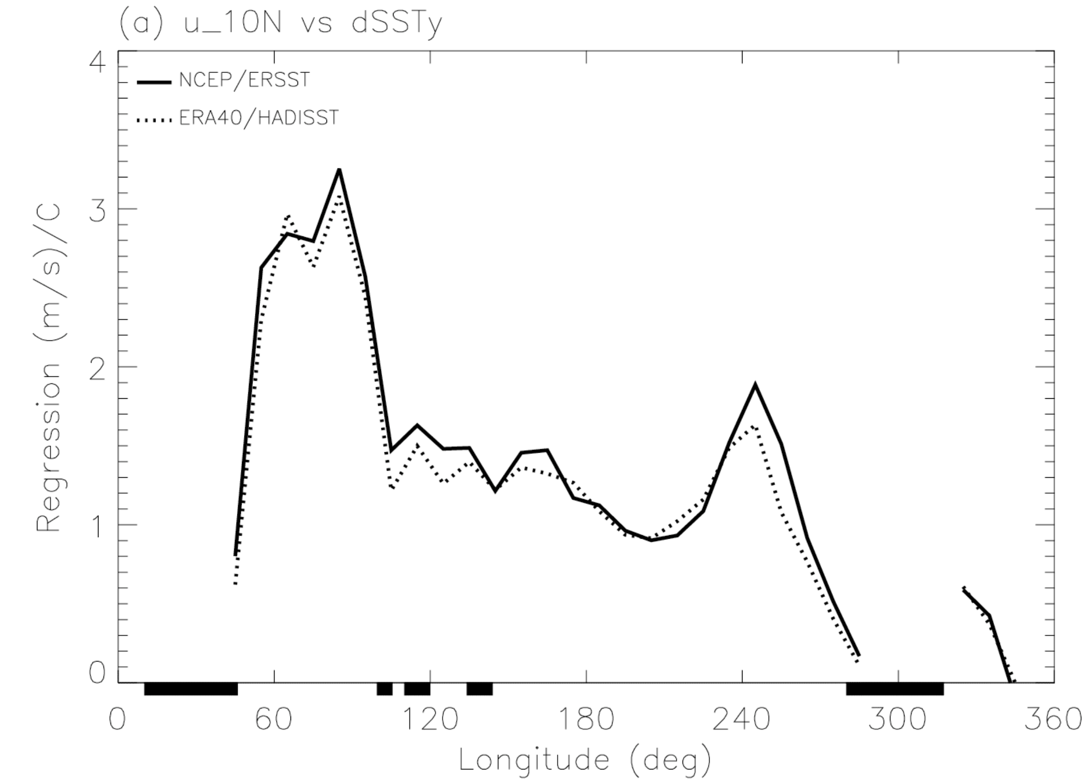

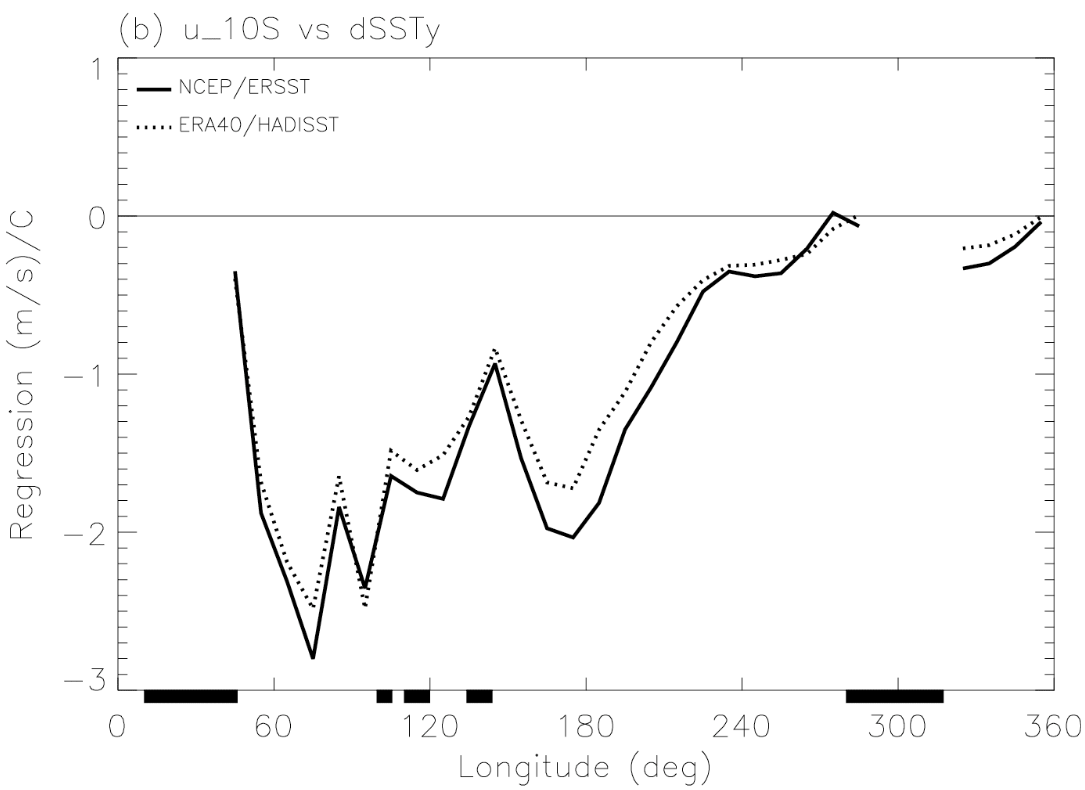

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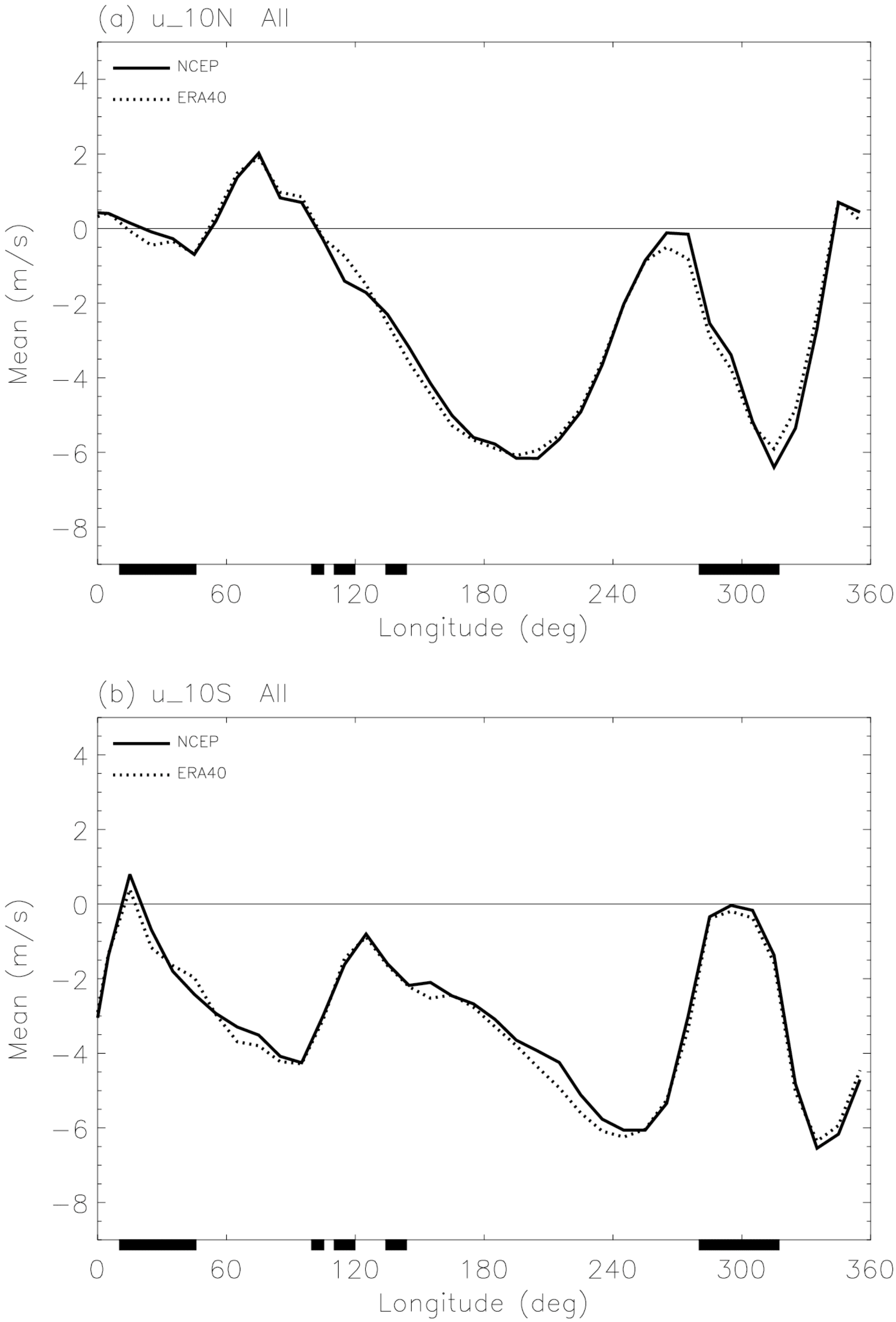

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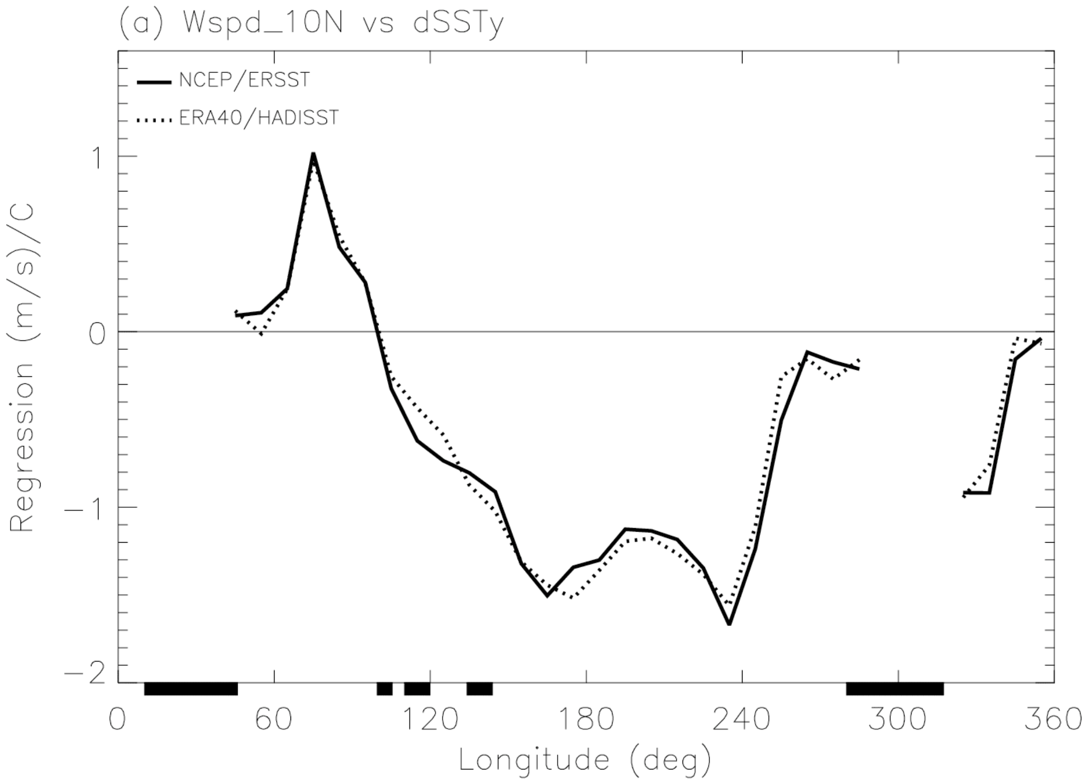

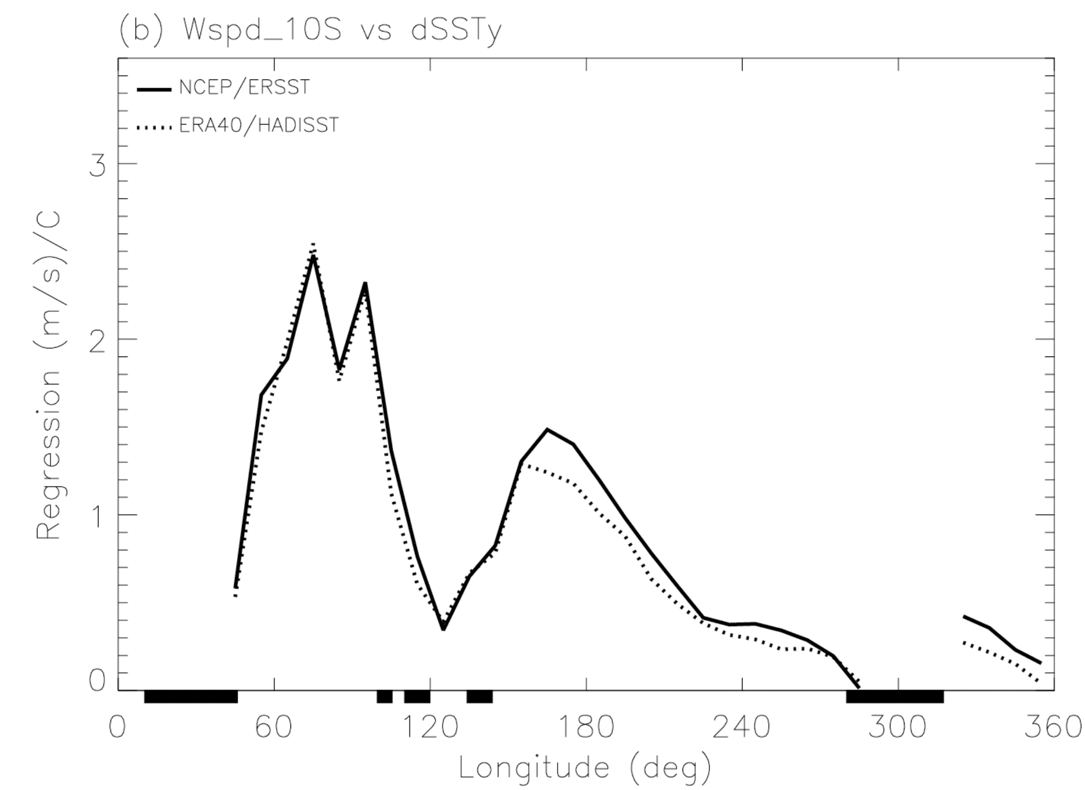

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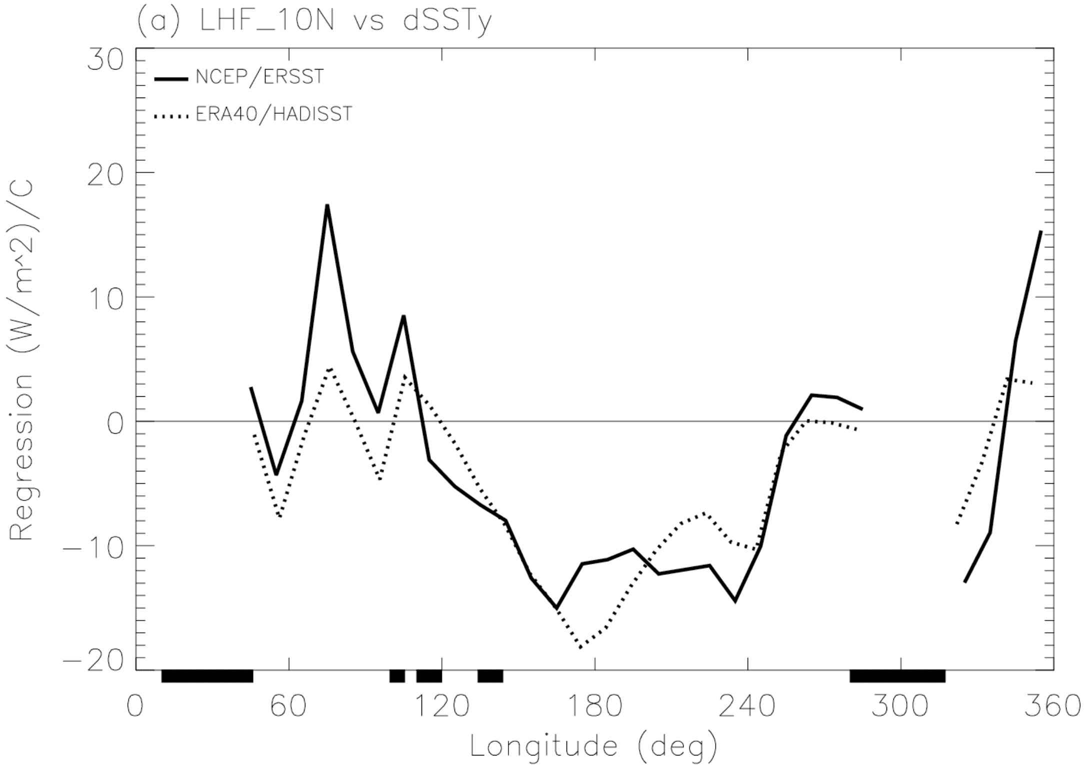

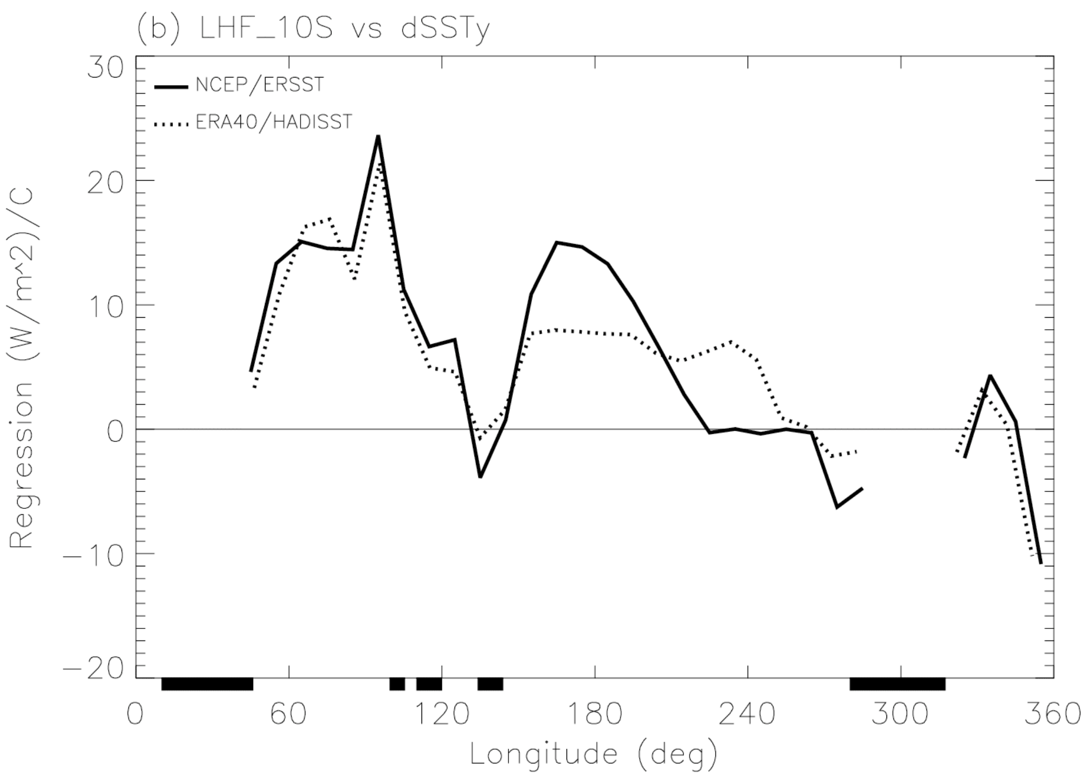

Figure 6. Same as Figure 1 but for (a) 5N-15N averaged LHF, and (b) 5S-15S averaged LHF vs ΔSST.